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# RELATIONSHIP OF FIELD TESTS TO LABORATORY TESTS OF MUSCULAR STRENGTH AND ENDURANCE, AND MAXIMAL AEROBIC POWER

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## ABSTRACT

The purpose of this study was to evaluate the relationship between established laboratory tests of selected physical fitness components and a field test battery (EXPRES) presently used annually to evaluate the physical fitness of CF personnel. Muscular strength, muscular endurance and maximal aerobic power ($\dot{V}O_2max$) were evaluated in 33 male personnel. The EXPRES test battery included isometric handgrip dynamometry as an indicator of strength, pushups and situps as indicators of muscular endurance, and $\dot{V}O_2max$ was predicted from the heart rate response to a submaximal step-test. The laboratory measures of strength consisted of maximal isokinetic and isometric contractions of the body's large muscle groups performed on a computerized strength evaluation system. Maximal power generated during a 30 s cycle ergometer sprint (Wingate Test) was used as the laboratory measure of muscular endurance. $\dot{V}O_2max$ was measured directly during exhaustive cycle exercise. When correlation coefficients were calculated for the various field and laboratory tests, the values ranged from 0.46 - 0.67 for muscular strength, 0.49 - 0.58 for muscular endurance, and 0.65 for $\dot{V}O_2max$. All correlation coefficients were statistically significant ($p<0.01$), but the standard errors about the regression lines were quite large. The EXPRES test battery is considered appropriate for the gross fitness evaluation for which it was designed, but users should be made aware of the rather large room for error in fitness evaluation. Seventeen of the subjects performed the EXPRES and the laboratory tests before and after 12 weeks of hydraulic resistance weight training. The laboratory test results suggested that training induced improvements occurred in all of the fitness components evaluated. The EXPRES test battery was not sensitive to these changes.

## INTRODUCTION

In view of the possible benefits of strength training in improving human performance during $+G_z$ exposure, a standard circuit training program has been introduced by the CF Directorates of Preventive Medicine and Physical Education, Recreation and Amenities (DPERA) at all bases where the CF-18 aircraft is presently, or will be, in service. The Applied Physiology Section, Biosciences Divison, at DCIEM was requested by DPERA to evaluate the effects of adherence to the training program on selected physiological and physical fitness components. The results, published separately (1), showed that twelve weeks of circuit training with hydraulic resistance equipment resulted in increased lean body mass, increased muscular strength, and increased maximal aerobic power (1).

DPERA is also interested in knowing whether the EXPRES fitness test battery (2) is a valid means of evaluating the adaptations to the program described above. In addition, the EXPRES test battery is being considered as a tool to test whether military personnel are able to meet, as yet to be determined, minimum physical fitness standards. Therefore, this report addresses two specific questions:

A. what is the relationship between EXPRES test values and established laboratory test values of muscle strength, muscular endurance, and maximal aerobic power ($\dot{V}O_2max$);

B. are there concomitant and commensurate changes in both EXPRES and laboratory test values after physical training.

## METHODS

**Subjects.** The subjects were 33 male personnel from CFB Moose Jaw who were aircrew, more specifically jet flight instructors and flight control personnel. Although several of the subjects were engaged in regular physical activity, none could be classified as an elite athlete. Their physical characteristics are described

in Table 1.

**Field Tests.** The subjects were tested during a two week period. The battery of EXPRES tests was administered during the first week under the supervision of the CFB Moose Jaw physical education and recreation instructors. Standard instructions were given to the subjects so that each test was performed as is described in the CF EXPRES Operations Manual (2). The EXPRES test measurement of muscular strength is the sum of the right and left hand maximal handgrip force as measured with an isometric dynamometer. Muscular endurance is measured as the number of pushups that can be completed and as the number of situps that can be completed in one minute. Indirect $\dot{V}O_2max$ is predicted from measurements of heart rate during a submaximal step-test (2,3).

**Laboratory Tests.** The laboratory tests were performed during the second week and were administered by experienced personnnel from DCIEM.

Muscular strength of selected muscle groups was evaluated on the Ariel Computerized Exercise (ACE) apparati. Documentation of the reliability and validity of the ACE has been reported previously (4). This equipment was used to measure force or torque production during maximum voluntary isometric and/or isokinetic contractions. After a warm-up of the muscle group to be tested, three maximal contractions were performed. If the force measured during the third contraction was more than 10% greater than either of the other contactions, the procedure was repeated. The following exercises were performed:

(a) supine bench press with the lever-arm controlled to move isokinetically at both relatively slow (10 °/s) and fast (45 °/s) velocities (note: the angular velocities refer to the velocity of the ACE lever-arm, not the anatomical levers);

(b) standing squats (knee extension) at the same velocities used for

the bench press;

(c) biceps curls (elbow flexion) at the velocities described above as well as isometrically with the inner elbow angle at 90°;

(d) sitting unilateral knee extension and flexion at relatively slow (30°/s), intermediate (100°/s) and fast (200°/s) velocities, and isometric extension with the knee at 90° of flexion.

The peak force or torque measured for each exercise was recorded as the maximal strength for that particular exercise.

The Wingate Anaerobic Test (5) was chosen as the laboratory test of muscular endurance. The test consisted of pedalling at maximal frequency for 30 s against a resistance of 75 g/kg body weight. A mechanically braked cycle ergometer (Cardionics) was used in which one pedal revolution caused a 6 m progress at the perimeter of the flywheel. For every 1/3 pedal revolution, an impulse was received by a pre-programmed calculator which printed out the average power output (in watts) for every 5 s period during the duration of the test. The calculated performance variables to be considered in this report are peak power which is the highest power output during any of the 5 s periods, the mean power generated during the 30 s, and a fatigue index calculated as the power output during the final 5 s expressed relative to peak power.

Direct $\dot{V}O_2$max was determined during exercise on a mechanically braked cycle ergometer (Monark) with a continuous, incremental, protocol (6). The pedalling frequency was 75 revolutions/min and power output was increased by 37 W/min until volitional termination or exhaustion. Expired gases were continuously directed into a Beckman Metabolic Cart where the mean oxygen uptake was automatically calculated for each 30 s period. The peak oxygen uptake measured was considered to be the $\dot{V}O_2$max.

Standard methods were employed to carry out hyrostatic weighing of the subjects in a swimming pool (7). Residual volume was predicted from age and direct measurement of forced vital capacity (8).

**Test Sensitivity to Training.** Seventeen of the subjects were tested with the EXPRES battery and laboratory test battery before and after 12 weeks of hydraulic resistance strength training. The details of the training and the effects on the laboratory test battery have been described previously (1). The effects on the field test battery results will be described in this report.

**Statistical Analysis.** The BMDP statistical software package (9) was used to derive the correlations between the lab and field measures as well as the means, standard deviations and ranges for all of the variables.

## RESULTS AND DISCUSSION

Mean values, standard deviations and ranges for the field and laboratory test batteries are listed in Tables 2 and 3, respectively. Table 4 lists the correlation coefficients calculated between the laboratory and field tests of the same fitness component. The pre and post training values for the laboratory and EXPRES tests for seventeen of the subjects are shown in Table 5.

**Strength.** Based on the present EXPRES classification system the subjects achieved only the minimum required for muscular strength for their age group. The correlation between handgrip force and the various laboratory strength tests were all statistically significant ($p<0.01$) and ranged from $r=0.46$ to $r=0.65$. The highest correlations were observed for isokinetic elbow flexion at the relatively rapid angular velocity, and for isokinetic knee extension at the relatively slow velocity. Although the correlation coefficients between the laboratory and field strength tests were statistically significant, Figures 1 and 2 show a large scatter of the data about the regression line.

A test of dynamic strength would be more reflective of actual strength demands than is the isometric handgrip test, but the desire for a field test that can be executed simply, quickly, and inexpensively has led to the use of maximal isometric handgrip strength. Tornvall (10) showed that static handgrip strength was correlated ($p<0.001$) with upper body and lower body isometric strength in a large military population. Bernauer and Bonanno (11) demonstrated a high correlation ($r=0.75$) between handgrip and elbow flexion strength, but their subject sample included both male and female subjects in contrast to the present study. Other studies have reported correlations similar to those we report for isometric handgrip strength vs. dynamic strength of other muscle groups (12-15). Dynamic and static muscular strength measures of identical muscle groups can be expected to be more highly correlated than when isometric strength of one muscle group is

compared to the dynamic strength of another muscle (14,15). This is supported by the results of the present study where the correlations for maximal isometric and isokinetic strength of the elbow flexors ranged from 0.48 to 0.65. The corresponding correlation coefficients ranged from 0.77 to 0.80 for the relationship between isometric and isokinetic knee extension.

The sum of the maximal forces and torques generated during the laboratory tests was used as a global indicator of strength and was plotted against handgrip force (Figure 3). The resulting correlation coefficient ($r=0.69$) was higher than when any individual laboratory strength test was plotted against handgrip force, confirming Tornvall's report of an identical correlation coefficient between handgrip force and the sum of maximal isometric forces of twenty muscle groups (10). These results support the use of static handgrip strength as a gross indicator of strength of larger muscle groups.

Strength training studies have demonstrated that handgrip strength is not significantly changed in spite of marked increases in strength of larger muscle groups (16,17). This finding was confirmed in the present study where there was no significant change in handgrip force in spite of increased strength in several of the laboratory strength tests (Table 5). In fact nine of the 17 subjects showed decreased maximal handgrip force after the 12 week strength training program. Thus, although the static handgrip test is useful for cross-sectional or inter-subject comparisons, its use to evaluate the short-term effects of strength training is questionable.

**Muscular endurance.** According to the EXPRES classification system, the present subjects are classified as good or excellent according to their scores for situps and pushups, respectively. The correlations between these field measures and indices of the Wingate Test were moderate, but statistically significant, ranging from 0.49 to 0.58.

The validity of the Wingate Anaerobic Test as a measure of anaerobic power and muscular endurance is well established (18-21). The arm cranking version is significantly correlated with sprint swimming performance times of competitive swimmers (20). The leg version, used in the present study, correlates with sprint running performance (21). Considering that different muscle groups are involved in each exercise, the significant correlations between the Wingate Test values and the pushups or situps were impressive. In terms of the sensitivity to strength training, pushups, but not situps, were significantly increased after training (Table 5). This is not surprising since no abdominal exercises were included in the training program (1).

**Endurance fitness.** Although the field and laboratory tests of $\dot{V}O_2max$ were more highly correlated than field and laboratory tests of other fitness components (Figure 4), only 42% of the variation in the direct measurement could be explained by the predictive method. Similar correlations between direct measurements of $\dot{V}O_2max$ and the step-test predicted values have been reported previously (22-24). The mean predicted $\dot{V}O_2max$ was significantly higher ($p<0.001$) than the mean directly measured $\dot{V}O_2max$ by 6.2 ml/kg/min. In one case this over-estimation amounted to 14 ml/kg/min which meant that some subjects were categorized as being highly fit when they were actually below average according to the present EXPRES classification system. A similar criticism of the use of this step-test as a predictor of $\dot{V}O_2max$ was raised by Bonen et al. (25).

It should be remembered that in both the present study and that of Bonen et al. (25) the $\dot{V}O_2max$ was detetermined during cycle ergometry, which can yield a 10 to 15% lower value than does treadmill ergometry (26). The difference between a 'true' $\dot{V}O_2max$ and the value predicted by a step test may be significantly smaller than that observed in the present study. When Bell and Allen (22) compared predicted and directly measured treadmill $\dot{V}O_2max$ values,

they found a mean difference of only 2 ml/kg/min for 97 subjects of varying ages and a correlation coefficient of 0.67. Although the prediction of $\dot{V}O_2$max by the step-test tends to consistently overestimate the maximal aerobic power of younger individuals and underestimate fit older individuals (22), it generally can be considered as being a valid and reliable means of evaluating the aerobic fitness of large numbers of subjects. With regard to training sensitivity, the subject sub-sample increased their predicted $\dot{V}O_2$max significantly but the mean increase was very small and within the methodological error of the technique used to predict $\dot{V}O_2$max (Table 5) (24).

## SUMMARY

A. Statistically significant correlations were measured between each of the EXPRES test components and an established laboratory test of the corresponding physical fitness component. However, the statistical significance of the relationships does not preclude major errors in fitness evaluation with the field tests. This point is aptly demonstrated in Figure 4, where the wide scatter of the data about the regression of the indirectly measured $\dot{V}O_2$max on the directly measured $\dot{V}O_2$max was so great that one subject was evaluated as being fit when he was very unfit.

B. The results suggest that the EXPRES test battery is not a sensitive tool to evaluate longitudinal adaptations to a short-term physical training program such as that prescribed for high performance aircraft personnel. In light of the consideration being given to minimum fitness standards for the CF, these results emphasize the necessity for the CF to have access to a laboratory test battery, such as that described in this report, when accurate, reliable, and valid physical fitness evaluations are required.

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**Figure 1.** The relationship of peak torque generated during maximal knee extension at a slow angular velocity to the sum of left and right hand maximal isometric handgrip force.

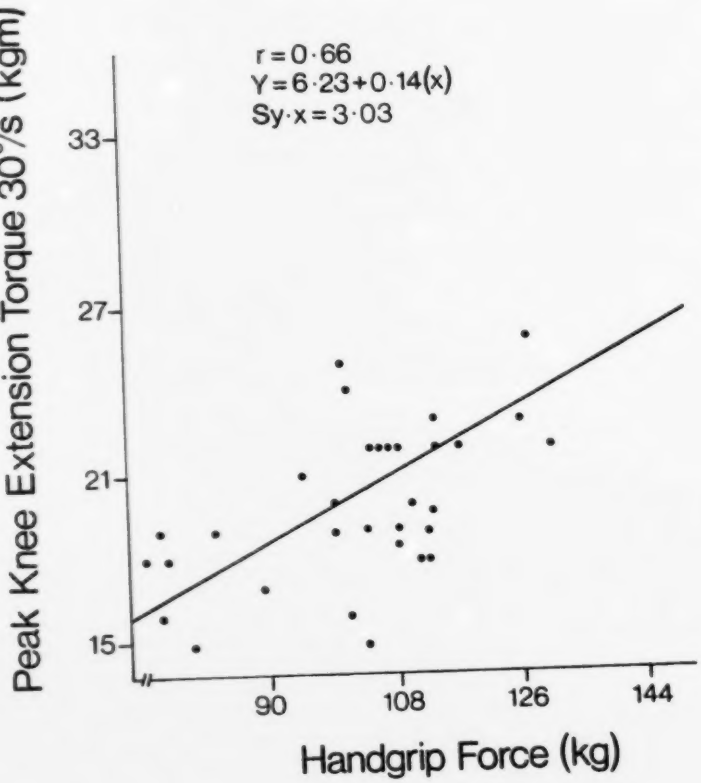

**Figure 2.** The relationship of peak force generated during elbow flexion at a fast angular velocity to the sum of left and right hand maximal isometric handgrip force.

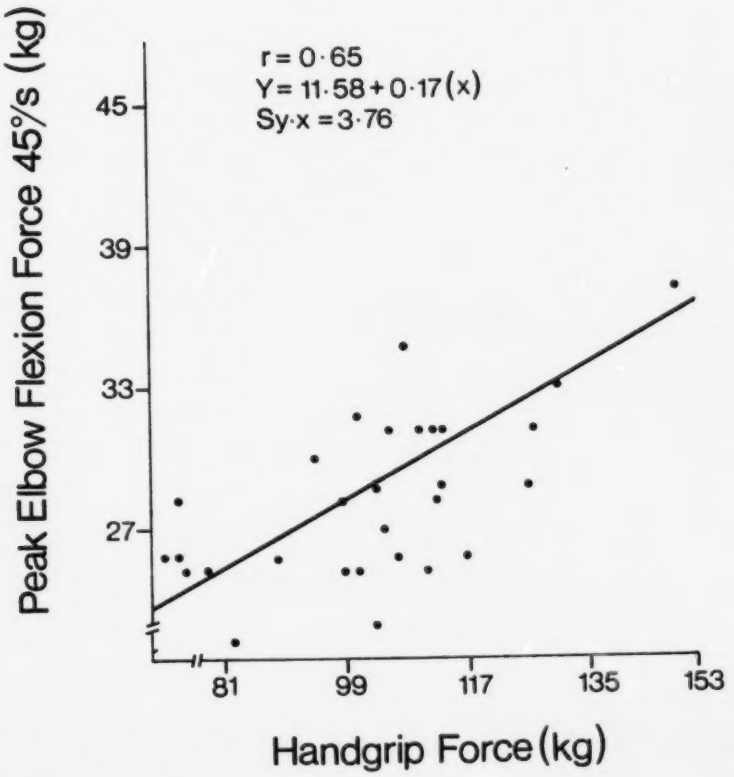

**Figure 3.** The relationship of an index of whole body strength to the sum of left and right hand maximal isometric handgrip force.

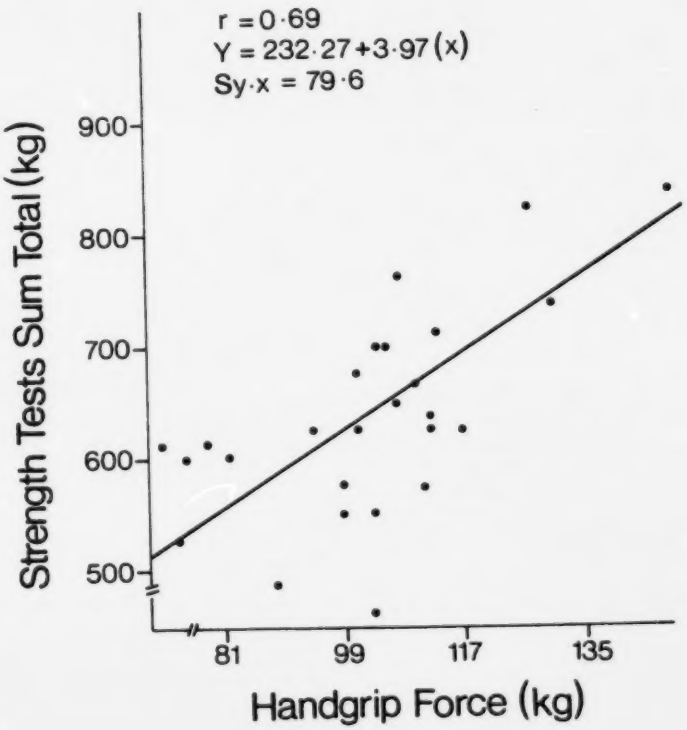

**Figure 4.** The relationship of directly measured $\dot{V}O_2$max during cycle ergometry to a predicted $\dot{V}O_2$max based on the heart rate response to step-test ergometry.

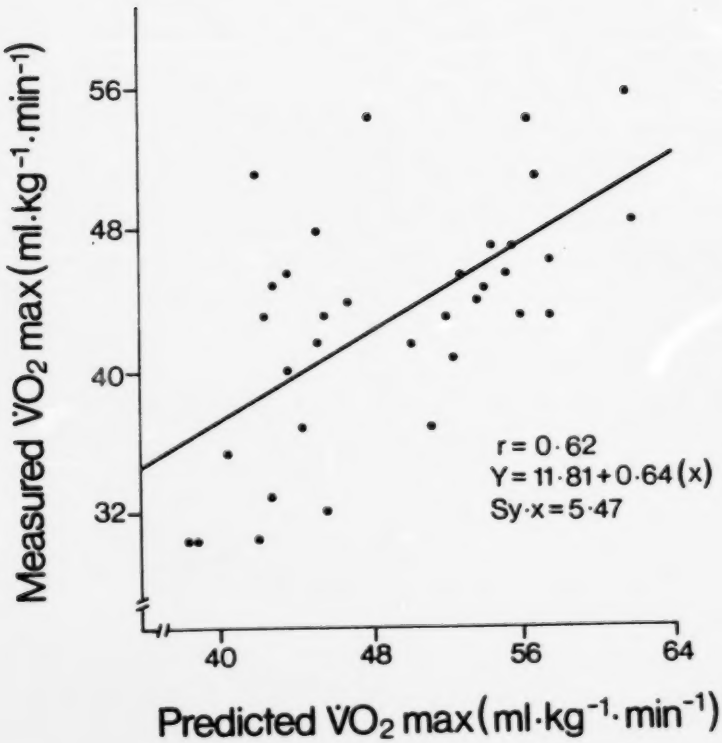

**Table 1.**
Physical characteristics of subjects (n=33 males).

| Variable | Mean | SD | Range |
|---|---|---|---|
| Height (cm) | 179.9 | 7.0 | 167.0-195.5 |
| Weight (kg) | 82.9 | 15.8 | 59.8-129.7 |
| Age (yrs) | 30.5 | 6.6 | 22-45 |
| Body Fat (%) | 17.6 | 8.6 | 4.7-46.0 |

**Table 2.**

Field measures of Table 2. Field measures of strength (sum of left+right hand isometric handgrip force), muscular endurance (pushups and situps), and maximal aerobic power ($\dot{V}O_2$max estimated from heart rate response to CHFT step test).

| Variable | Mean | SD | Range |
|---|---|---|---|
| Handgrip force (kg) | 104.4 | 18.8 | 72.0-148.0 |
| Pushups (number) | 39 | 16 | 12-90 |
| Situps (number) | 39 | 11 | 16-56 |
| Predicted $\dot{V}O_2$max (ml/kg/min) | 49.0 | 6.8 | 38.6-61.9 |

**Table 3.**
Laboratory measurements of muscle strength, muscular endurance as indicated by Wingate Test indices, and maximal aerobic power.

| Exercise | Units | Mean | SD | Range |
|---|---|---|---|---|
| *Strength* | | | | |
| Bench press 10 °/s | kg | 93.1 | 19.9 | 60-143 |
| 45 °/s | kg | 42.8 | 8.4 | 28-62 |
| Squatting knee extensions 10 °/s | kg | 183.7 | 35.3 | 116-265 |
| 45 °/s | kg | 91.7 | 19.8 | 62-156 |
| Elbow flexion 10 °/s | kg | 48.7 | 9.0 | 37-72 |
| 45 °/s | kg | 28.7 | 4.7 | 22-47 |
| isometric | kg | 42.0 | 5.6 | 33-58 |
| Sitting knee extensions 30 °/s | kgm | 20.5 | 4.0 | 15-35 |
| 100 °/s | kgm | 17.9 | 3.3 | 13-28 |
| 200 °/s | kgm | 15.4 | 2.4 | 12-23 |
| isometric | kgm | 26.6 | 6.8 | 15-43 |
| Sitting knee flexions 30 °/s | kgm | 12.7 | 2.7 | 7-21 |
| 100 °/s | kgm | 12.1 | 2.3 | 9-21 |
| 200 °/s | kgm | 11.1 | 2.3 | 8-21 |
| *Muscular Endurance* | | | | |
| Wingate test peak power | W/kg | 10.4 | 1.3 | 7.9-12.2 |
| Wingate test mean power | W/kg | 7.7 | 1.1 | 5.4-9.4 |
| Wingate test fatigue index | % | 52.0 | 9.2 | 23.3-71.8 |
| *Maximal Aerobic Power* | | | | |
| $\dot{V}O_2max$ | ml/kg/min | 42.8 | 7.3 | 24.0-56.2 |

**Table 4.**

Pearson correlation coefficients between selected field and laboratory measures of strength, muscular endurance and aerobic power.

| Laboratory Test | Field Test | Correlation Coefficient |
|---|---|---|
| *Strength Measurements* | | |
| Bench press (10°/s) | Handgrip | 0.62 |
| Bench press (45°/s) | Handgrip | 0.62 |
| Squat (10°/s) | Handgrip | 0.51 |
| Squat (45°/s) | Handgrip | 0.59 |
| Elbow flexion (10°/s) | Handgrip | 0.60 |
| Elbow flexion (45°/s) | Handgrip | 0.67 |
| Elbow flexion (isometric) | Handgrip | 0.49 |
| Knee extension (30°/s) | Handgrip | 0.66 |
| Knee extension (100°/s) | Handgrip | 0.62 |
| Knee extension (200°/s) | Handgrip | 0.53 |
| Knee extension (isometric) | Handgrip | 0.50 |
| Knee flexion (30°/s) | Handgrip | 0.50 |
| Knee flexion (100°/s) | Handgrip | 0.46 |
| Knee flexion (200°/s) | Handgrip | 0.46 |
| *Muscular Endurance Measures* | | |
| Wingate peak power | Situps | 0.54 |
| Wingate peak power | Pushups | 0.54 |
| Wingate mean power | Situps | 0.58 |
| Wingate mean power | Pushups | 0.49 |
| Wingate fatigue index | Situps | 0.25 |
| Wingate fatigue index | Pushups | 0.03 |
| *Maximal Aerobic Power Measures* | | |
| Direct $\dot{V}O_2$max | Indirect $\dot{V}O_2$max | 0.65 |

**Table 5.**
Laboratory and field test values for 17 of the subjects before and after 12 weeks of hydraulic resistance training.

| Test | Pre | Post | Mean Change | Mean Relative Change (%) |
|---|---|---|---|---|
| *Maximal Aerobic Power* | | | | |
| Indirectly measured $\dot{V}O_2$max ml/kg/min | 47.4 | 48.6 | 1.2 | +2.5 |
| Directly measured $\dot{V}O_2$max ml/kg/min | 42.8 | 46.7 | 3.9 | +9.1*** |
| *Muscle Strength* | | | | |
| Handgrip force kg | 101.6 | 100.2 | -0.7 | -1.4 |
| Squats 10°/s kg | 171 | 200 | 29 | +17.4*** |
| Bench press 45°/s kg | 37.3 | 43.7 | 6.4 | +17.2*** |
| *Muscular Endurance* | | | | |
| Pushups number | 32.7 | 37.5 | 5.9 | +14.7** |
| Situps number | 36.5 | 37.9 | 1.4 | +3.8 |
| Wingate test mean power W/kg | 7.6 | 7.8 | 0.2 | +2.6* |
| Wingate test fatigue index % | 51 | 55 | 4 | +7.8* |

Values are means.
***$p<0.001$, **$p<0.01$, *$p<0.05$